BENTON HARBOR POWER PLANT LIMNOLOGICAL STUDIES

PART VIII. WINTER OPERATIONS 1970-1971

John C. Ayers
Norbert W. O'Hara
William L. Yocum

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INTRODUCTION

In Part VII (March 1971) of our report series relative to the Donald C. Cook Nuclear Station, we established the following report format:

A. COOK PLANT PREOPERATIONAL STUDIES

- A.1 Recording of Local Water Temperatures
- A.2 Study of Floating Algae and Bacteria
- A.3 Development of a Monitor for Phytoplankton
- A.4 Study of Attached Algae
- A.5 Study of Zooplankton
- A.6 Study of Aquatic Macrophytes
- A.7 Study of Benthic Organisms
- A.8 Study of the Local Fishes
- A.9 Support of Aerial Scanning

B. SURVEYS OF EXISTING WARM WATER PLUMES

C. THE ICE BARRIER AT THE COOK PLANT SITE

D. EFFECTS OF EXISTING THERMAL DISCHARGES ON LOCAL ICE BARRIERS

E. EFFECTS OF RADIOACTIVE WASTES IN THE AQUATIC ENVIRONMENT

- E.1 Gamma Scan of Bottom Sediments
- E.2 The Most Sensitive Organism for Concentration of Radwastes
- E.3 Study of Lake Michigan's Present Radioactivity Content (FINISHED)

This report covers only items C and D of the above format; all the others were brought up to date in Part VII referenced above. At the time of that report, these studies were incomplete.

C. THE ICE BARRIER AT THE COOK PLANT SITE

Each winter the eastern shore of Lake Michigan forms a substantial barrier of ice along its beaches and in the nearshore water. The ice barrier justly has been credited with protecting the shore from wave action by its presence, and blamed for causing shore erosion during its breakup.

Concerned citizens commonly charge that waste heat from generating stations will melt away the barrier of shore ice and expose their beaches to the erosive effects of winter waves.

The essential barrier against winter-wave beach erosion is the icefoot. Located along and just landward and lakeward of the water's edge, this barrier forms a compact ice complex.

Marshall (1966, p. 31)* says, "An icefoot can be composed of any combination of frozen spray or lake water, snow accumulations, brash, stranded ice floes, and sand which is either thrown up on the icefoot by wave action or is blown out from the exposed beaches." With such a variable composition, and in the absence of literature specific to the ice of the local area, we have carried out studies to determine the mode of formation, composition, variability, and duration of the icefoot and the other components of the shore ice structure.

The studies have been centered upon, but not limited to, the area of the Donald C. Cook Nuclear generating station, south of Benton Harbor, presently under construction.

From aerial photographs and ground and water observations, there is no apparent difference in the basic structure of the shore ice from Sleeping Bear Dune in northern Michigan to the Bailly Station at Burns Harbor, Indiana. The shore

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*Marshall, E. W. 1966. Air photo interpretation of Great Lakes ice features. Special Report No. 25, Great Lakes Research Division, University of Michigan, Ann Arbor, Mich. ix and 92 pp., 64 figures.

ice structure of this stretch of shoreline is almost exactly the same as that presented in Fig. 28 by Marshall (1966). From this figure a storm icefoot of ice ridges can be observed immediately along shore. Lakeward of the icefoot is a frozen lagoon of ice floes beyond which is located an offshore barrier bar of ice. Figure 1 is a photograph from Marshall's work depicting the "anatomy" of the basic shore ice structure discussed above.

This report summarizes a much larger and more detailed report, and is illustrated with selected pictures from that report. To avoid confusion in identifying pictures, each retains in parentheses the figure number that it has in the full report.

Because this paper requires constant comparison of text or figure legend to the appropriate color photograph, and because descriptive narrative always refers to the slide being observed, the text and figure legends are written in the present tense.

Because of the expense of duplicating the large number of color photos involved, the full report is being prepared in only two copies. One copy will be presented to the Michigan Water Resources Commission as a research tool; the other will be retained on file by the Great Lakes Research Division.

This report describes and depicts the essential stages of development of the shore ice structures as they are understood after two winters of study.

Stages of Icefoot Formation

1. *The Frozen Beach*

The initial stage of icefoot formation consists of a condition in which the beach, having been wetted by rain or spray, is subjected to freezing temperatures before its surface dries. Figure 2(5) gives a general view of the frozen beach while Figure 3(9) shows the frozen sand surface at water's edge where small-scale undercutting of the frozen beach is in progress.

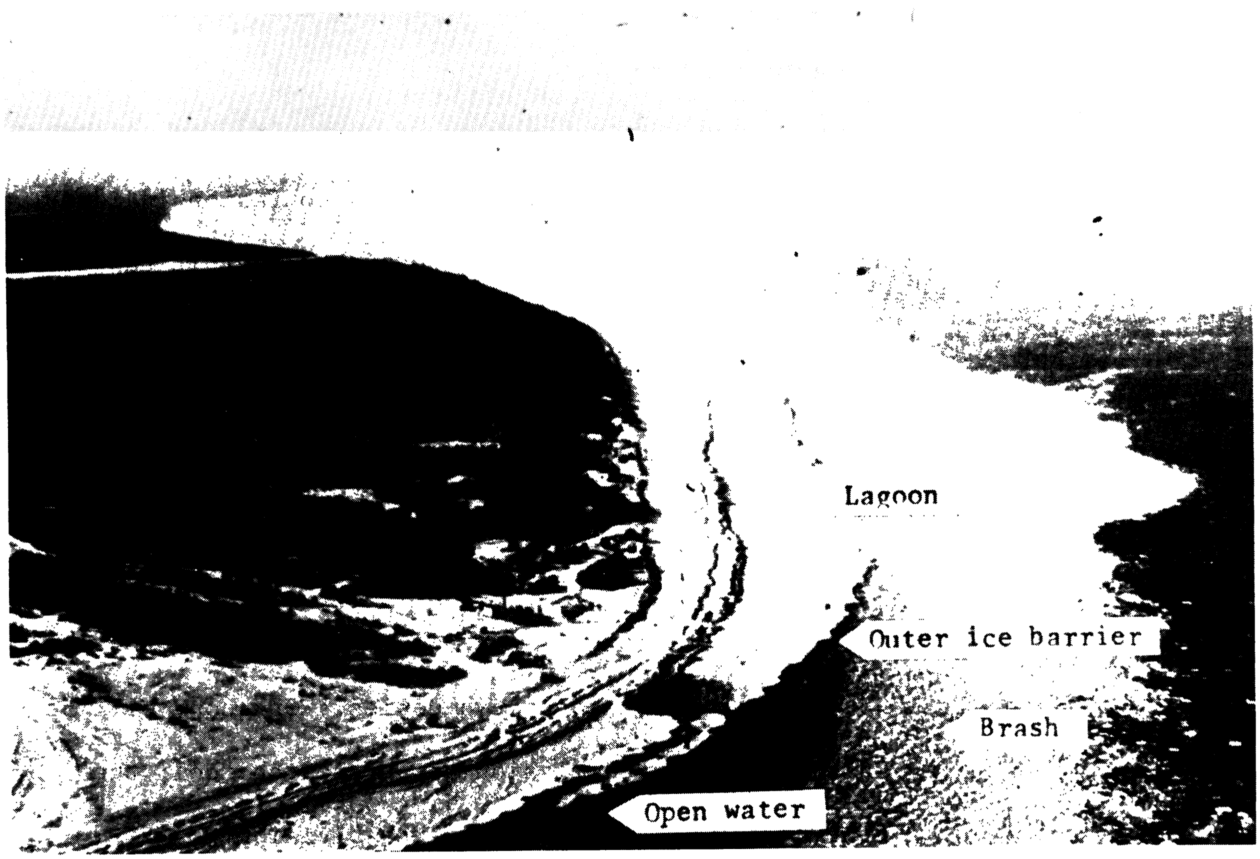

FIG. 1. The general arrangement of the shore ice structure. The icefoot is the series of narrow ridges against shore. Marshall 1966, Fig. 28.

Marshall's legend reads: "Fig. 28. STORM ICEFOOT WITH A LAGOON AND OFFSHORE BARRIER. The inner terraces reflect a series of storm accumulations on a shoreline where portions are moderately sloping. The lagoon between the inner and outer barrier is filled with frozen brash, possibly grounded. The outer ice barrier marks the position of an offshore bar, while loose brash drifts outside this barrier. Lake Superior (Whitefish Point, Mich.) 1/14/65."

2. *The Frozen-Spray Covered Beach*

Present evidence indicates that the second stage of icefoot formation consists of a condition, probably short-lived, in which the frozen beach receives a glaze of storm-spray ice. This condition is shown in Figure 4(14) wherein a slab of frozen sand has been thrown from water's edge back upon the beach and coated by spray ice.

3. *The Simple Tabular Ice*

The very storm conditions that produce the spray-ice covered beach are also responsible for the production of simple tabular ice at the water's edge, the third stage of icefoot formation.

The lakeward edge of the spray-ice covered beach presents an obstacle against which the storm waves break. The large waves throw spray well up the beach while smaller waves deposit their freezing spray near the lake. There being more small waves than large ones, ice accumulates faster at the edge of the beach than farther back on the beach. The result is a flat-topped wedge of ice which fills in the slope of the beach and the nearshore lake bottom. This condition, shown in Figure 5(15), is considered to be transient, for the waves continue to break against its vertical face and to deposit more material at the outer edge than further landward.

4. *The Simple Ice Rampart*

Continued deposition of spray, slush, and ice balls on the lakeward edge of the ice sheet builds up the edge into an elevated ridge of ice with a vertical face along and just lakeward of the water's edge. Undercutting by waves produces cracks in the ice rampart. Waves pocketed in undercuts force water and sand upward through the cracks, eroding some of them into blowholes. Figure 6(20) depicts the simple ice rampart condition. Undercutting and cracking are shown in the foreground and two newly developed blowholes show beside the man in the middle distance.

5. *The Developed Ice Rampart*

Continued wave activity builds ice cones around the mouths of the blow-holes. This condition may be considered a "mature" stage of the ice ridge, for its high lakeward face favors undercutting and collapse. Figure 7(22) presents this stage of the ice rampart.

6. *The Collapsed Rampart*

Wave undercutting, cracking, collapsing of blocks of the rampart, and the melting action of sunlight warming the sand incorporated into the ice all act as destructive forces to lower and compact this rampart. These conditions are illustrated in Figure 8(24). Figure 9(25) shows the melting effect produced when the sun warms sand incorporated in the ice.

The above stages appear to be the sequence of events that lead to the establishment of a first ridge of ice immediately along the shoreline. This is the first ridge of the icefoot and for discussion purposes is designated Ridge A.

As the result of increasing wave action from north to south in the Cook Plant area, most of the above stages were present in a progressive sequence from north to south on 29 December 1970.

7. *The Formation of Ridge B, The Second Ridge of the Icefoot*

Ridge A may wax and wane after its initial formation, as the accretive forces of new storms, delivering ridge materials, overmatch or undermatch the destructive forces of undercutting, breaking off, collapsing, and melting.

Eventually, however, there arrives a push of floe ice ("brash" in Marshall's terminology) which piles up, reaches to bottom, and freezes into a second ice ridge close against and just lakeward of Ridge A. The presence of Ridge B shuts off wave action from Ridge A, and further accretion to this ridge is stopped. The destructive forces, however, continue to operate and Ridge A becomes progressively lower, more compact, and more sandy as can be seen in later figures.

Figure 10(31) shows in the background a push of brash which became Ridge B in the winter of 1969-70.

Along the eastern shore of Lake Michigan during the two winters of our study two icefoot ridges have been the rule, though three have been indicated in a few of our photographs. Marshall's storm icefoot in Lake Superior (Fig. 1) appears to indicate four such inshore ice ridges in that icefoot.

Formation of the Frozen Lagoon

After establishment of the icefoot (during which Ridge B may occasionally develop blowhole activity) there eventually arrives a set of brash (or flow ice) which covers the lakeward side of Ridge B and becomes solidified by spray-cementing, direct edge-to-edge freezing, and/or by the freezing of interstitial slush formed from snow wind-swept into the intervals between floes.

Figure 11(34) shows at left the nature of the frozen lagoon. At present our evidence indicates that ice over the lagoon may have water below it.

Formation of the Outer Ice Barrier (Ridge C)

Shortly after the ice floes that make up the frozen lagoon have arrived and solidified, their outer (lakeward) edge becomes subjected to wave action which breaks off some parts and loads the surface of the remaining outer edge with a burden of spray ice, iceballs, slush, and sand that we suggest thickens the outer edge of the lagoon ice until it has become solidly grounded on the lake bottom after which the height of the ridge increases.

This outer ridge we have designated for convenience of reference as Ridge C. Figure 12(36) shows our concept of the basic eastern Lake Michigan shore ice structure. Ridge A, in the right middle distance, is low, compacting, and sandy. Ridge B, in the right foreground is higher than Ridge A and somewhat sandy. The lagoon ice, at left foreground to center middle distance, is frozen brash. From the left Ridge C extends to the right distance as a distinct line of conical and

sub-conical elevations with definite sandy color. Over the top of Ridge C in the left center distance a limited field of brash is visible.

As was the case for Ridge A, and probably Ridge B, Ridge C waxes and wanes under the same accretive forces and the same destructive factors. This will be illustrated later.

Formation of the Second Lagoon and the Second Outer Barrier (Ridge D)

During the dead of winter along the eastern shore of Lake Michigan it is not uncommon for a second frozen lagoon and outer ice barrier to form. This second outer barrier we have designated as Ridge D. Apparently the second lagoon and Ridge D form in the same way as the inner lagoon and Ridge C. It is of interest to note that Ridge D not only can develop into the highest of the ridges but that it also appears to increase in thickness until it becomes grounded on the Lake's inner sand bar at a distance of about 500 feet from shore.

Also in the dead of winter extensive fields of brash may move into an area and temporarily solidify on the lakeward side of Ridge D. However, these fields of ice soon break up and move away. On 2 February 1971 the tocal ice field off the Cook Plant site reached to 10.5 miles offshore. By the end of the day the ice field had broken up and the ice coverage was reduced to the area shoreward of Ridge D. This is discussed and illustrated in the full report.

The condition of shore structure on 24 February 1971 is shown in Figure 13(74). In this figure Ridges A, B, the inner lagoon, Ridge C, the outer lagoon, Ridge D, and a still outer field of brash are all visible, with the Cook Plant in the background. We have only aerial photographic evidence as to the nature of the fields of brash ice that form temporarily outside Ridge D. Evidently they are not too solid, for they vanish quickly. We do, however, have solid evidence as to the nature of the second ice lagoon and of the second outer ice barrier (Ridge D).

Figure 14(77) presents an overview of the conditions of the shore ice

structure off the Cook Plant site on 26 February 1971 when the basic shore ice, the second lagoon, and Ridge D were present without the complication of brash ice fields to lakeward. From the foreground the following features can be observed: the beach, Ridge A, Ridge B, the inner lagoon, Ridge C, the second lagoon, and Ridge D. The heavily sand-laden conditions of the three inner ridges are clearly evident.

Details of the Shore Ice Structure at Maximum Development

The following pictures were taken by Dr. O'Hara on 26 February 1971 off the Cook Plant site during an observation and study walk from the beach out to the lakeward face of Ridge D.

Figure 15(80) is a view northward along Ridge B, Ridge A lies in the right middle distance; Ridge C lies in the left three-quarters distance. All three ridges are heavily sand-laden as a result of sand concentration, by solar heat on the sand particles and ice evaporation.

Figure 16(85) is of the lakeward face of Ridge C with ice of the outer lagoon at the right. The nature of the lagoon ice shows its floe ice origin.

Figure 17(88) shows a natural cross section of Ridge C where it had been breached by waves. The surface of the ridge is covered with sand. Layers of spray ice show above the shovel handle and a layer of spray ice with iceballs can be observed behind the shovel handle.

In Figure 18(89) a saw cut has been made through the spray ice layers. The layers both taper toward the beach and tilt downward toward the beach. Limited amounts of sand are present in the thin layers.

Figure 19(90) is a saw cut through the spray ice and iceball stratum.

In Figure 20(91) is shown an anticlinal pressure feature in the ice of the second lagoon about 10 meters west of Ridge C. Four large sandy pieces of pancake ice show in the background.

Figure 21(92) is a view from the shoreward edge of Ridge D back across the

second lagoon to Ridge C. On 2 March the width of the second lagoon was estimated by pacing to be about 80 meters.

Figure 22(93) looks southward from the shoreward side of Ridge D.

The face (lakeward edge) of Ridge D is shown in Figure 23(95). The ridge is laden with sand except where new clean slush-spray ice is being accumulated along the edge. The man stands on top the ice cone of a blowhole, estimated to be 25 feet high, which was the highest point on the local ridge.

Figure 24(96) shows ice blocks, iceballs, and slush/spray ice in Ridge D, after the sand covering had been scraped away.

On 2 and 3 March 1971 Dr. O'Hara again visited the Cook Plant site to observe particularly Ridge D and the second lagoon. It proved to be a very fortunate visit, for the spring breakup began on 3 March and his visit to Ridge D and the second lagoon would not have been possible after 2 March. On 2 March Ridge D was a discontinuous series of blocks, with one stretch of solid ice in the second lagoon which gave access to a block of Ridge D offshore on the north side of the construction site.

Figure 25(116) shows at right a large and recently active blowhole in the face of Ridge D, while in the center, wave action is depositing new slush/spray and iceball material in a breach of the ridge.

During this time the water was making rapid additions to the ice ridges. The reason for this is shown in Figure 26(118); the water at the face of any exposed ridge was loaded with pancake ice, iceballs, and literally grey with slush; air temperatures were still low and the freezing regime was still dominant, though not so strongly as had been the case somewhat earlier in the year.

In the morning of 3 March, under a northwest breeze, the ice of the second lagoon (between Ridges C and D) was flexing and breaking up. Figure 27(126) shows, at about 1000, the isolated block of Ridge D which had been visited on 2 March. The solid section of second lagoon ice that had provided access to the isolated

chunk of Ridge D the day before has now become broken and is being carried away.

Figure 28(127) gives the condition of the same area at about 1400 on 3 March. All the remaining ice of the second lagoon has been broken up and removed by increasing wind from the northwest.

The rising wind and the heavy content of ice, slush, and iceballs in the water gave, later in the afternoon of 3 March, a dramatic demonstration of the rejuvenation of an ice ridge (in this case Ridge C).

Figure 29(129) depicts rapid augmentation of Ridge C by the readily freezable contents of the water that is being thrown upon it. Ridge B in the right foreground is, and has been, sheltered from such activity. On this ridge the action of solar energy upon the sand incorporated into the ice has not only covered the ridge with a lag-concentrate of sand, but has produced differential melting of the iceballs within the ridge.

Figure 30(130) is a detail of the surface of Ridge B at the time Ridge C was receiving active augmentation on 3 March. Sun-warmed sand has melted the ice, and in doing so has accumulated on the ice surface. Iceballs of Ridge B have been sun-melted to about the degree that they contained sand in their ice.

Figure 31(131), taken later in the afternoon of 3 March, shows not only extensive augmentation of Ridge C but an active blowhole.

Still later in the afternoon other blowholes in the area off the Cook Plant construction site were active. Figure 32(137) shows one of these and slush/spray being deposited onto the face of the ridge to the right.

In Figure 33(140) a wave breaking onto the face of Ridge C is caught in the act of throwing spray, slush, and iceballs onto the face of the ridge.

The Demises of the Shore Ice

The Quiet Demise

In the spring of 1970 the shore ice departed quietly. Figure 34(141) shows

Ridge A at right against the shore, Ridge B in the center, remnants of Ridge C and the first lagoon at left. This picture was taken on 5 March 1970.

On 16 March 1970 there was a badly wasted Ridge A at right, a modest Ridge B in center, and at left a refrozen lagoon with remnants of Ridge C in the left three quarter distance. These conditions are shown in Figure 35(148).

On 23 March 1970 the conditions along the Cook Plant's north shore were as shown in Figure 36(154). In this figure scattered portions of Ridge A extending above water can be observed along the right. Ridge B, shown in the center, was low and heavily sand-laden. Isolated pieces of Ridge C are evident at the left, with loose lagoon ice located between Ridges B and C.

Figure 37(164) gives the conditions along the Cook Plant's north beach on 30 March 1970 at the end of the ice season. A small ridge of sand parallel to shore probably represents the sand that had been incorporated into Ridges A and B.

The ice departure at Cook Plant in the spring of 1970 was merely a quiet melting-in-place, and did not produce shore erosion. However, this was not the condition of demise that prevailed in the spring of 1971.

The Storm Demise

A strong storm on 19 March 1971 completely changed the pattern of the lake's entry into the spring no-ice condition.

Figure 38(150) illustrates the ice conditions northward from the Cook Plant construction site on 17 March 1971. Ridge A shows against the beach at right and is heavily sand-laden; Ridge B shows in the right center and is also sand-laden, though not to the degree of Ridge A; Ridge C still high and with some white-ice augmentation extends to the right across the picture from left middle distance. The ice of the first lagoon between Ridges B and C is broken.

Figure 39(152) presents a view northward along the beach from the Cook Plant site on 22 March 1971. The remains of older ice ridges are on the beach, and the

water along the beach is heavily laden with slush and iceballs.

On 25 March the general view along the beach to the north of the Cook Plant construction site was as shown in Figure 40(157). Large remnants of the old shore ice structure are on the beach, and a new icefoot has begun to form from pancake ice, slush/spray, and iceballs. South of the Cook Plant site this condition was not present.

Figure 41(158) shows spray-ice covered blocks of frozen sandy ice pushed up onto the beach, probably the remnants of old Ridge A. There is no evidence of the "quarrying" of blocks of frozen beach, as was the condition south of the Cook Plant site.

South of the Cook Plant site, where the beach appears to be subject to more rigorous wave action, the conditions of ice on the beach on 25 March are represented in Figure 42(159). This view looking northward along the beach from near Bridgman, Michigan, shows the cranes of the Cook Plant construction site in the right middle distance. Pushed blocks of Ridge A or of frozen beach are visible in the lower right.

Figure 43(161) shows quarrying of the frozen beach by movement of ice that was frozen to the beach near Bridgman, on 25 March 1971.

SUMMARY

These observations have been made possible by two years of excellent routine photography by Redman and Ames of Benton Harbor, and by the cooperation of the Cook Plant construction personnel among whom Robert Lawson and Jon Barnes must be singled out for special thanks.

During the two winters of observation the Lake Michigan beach in the Cook Plant area has exhibited a pattern of developing a basic icefoot with an offshore frozen lagoon and an outer ice barrier. We regard this condition as the basic

shore ice structure, which is in accord with one of the modes of shore ice development presented by Marshall (1966). During late winter the Cook Plant site develops a second frozen lagoon and a second outer ice barrier that are embellishments upon the basic shore ice structure.

At fullest (temporary) maturity the shore ice structure at the Cook Plant site may consist of an icefoot composed of two ridges of onshore ice, a frozen lagoon of ice floes, an outer barrier of ice, a second frozen lagoon, a second outer barrier, and finally a transient field of floe ice of limited durability but which reached a surprising extent of 10.5 miles on 2 February 1971.

The ice ridges and lagoons of the shore ice structure build up as frozen spray, freezing slush, small ice cakes, ice balls, and sand from the bottom, are all added at the lakeward edge of the ridge. In addition, snow is trapped behind (shoreward) the ridges and solidified by spray coming over the ridge, and windblown sand from the beach is deposited on and incorporated into the ridges and lagoon ice. Except for windblown snow and sand, the accretionary processes go on only on that ridge which is currently exposed to the open lake; lagoon ice or the development of a ridge further offshore shuts off the necessary wave action against the ridge face, and its growth ceases.

The same wave action that is a major necessity for ridge augmentation has in it, also, the seeds of ridge destruction. Violent wave action can break up a ridge and reduce it to floe ice or brash. Less-than-violent wave action, even when the water is freezing-cold and slush-laden, still will undercut ice ridges by excavating bottom sand from beneath them; removal of foundation support results in the collapse of ridge sections. Undercutting appears to be effective only during the active formational period of the icefoot ridges.

Strong, but less than violent, wave action (probably aided by collapse of undercut ridge parts) will produce local breaches through ice ridges; the removal

of ridge ice contributes to the floe ice.

In addition to direct physical destruction by violent wave action, and to undercutting and collapse of ridge portions during less violent wave conditions, wave action throws bottom sand either directly over the ridge face or blows sand up through blowholes. In both cases the sand is incorporated (along with windblown beach sand) into the ridge by being covered by subsequent spray ice, slush ice, or snow solidified by spray and freezing.

Regardless of its origin, sand incorporated in the ice acts as a dark body and absorbs solar energy. Being warmed, it melts the underlying ice and settles into it. As successive sand increments are added to the upper sand layer by this process the total sand accumulated during the dark-body melting process lies on the surface as a lag-concentrate. The more sand accumulated by this process, the thicker and more continuous the surface sand layer becomes, and the more effective it becomes as an accumulator of solar energy and consequently the more effective it becomes as a melting agent of the underlying ice. Sand-melting of ice continues in the ice ridges and lagoon ice even after other ridges or lagoons further offshore have stopped wave action and deprived them of the means of rejuvenation.

The total picture of ice ridges and lagoons is a dynamic and changing one. Exterior ice fields, second outer ice barriers, and second lagoon ice are transient and apt to be carried away as the result of wave flexing and wind or current pressure. Ridge C, the normal outer barrier of the shore ice structure, can be broken up or breached but so long as the weather and the water remain sufficiently cold the rejuvenating processes will begin and restoration will be made.

Basically, the construction, maintenance, and destruction of the shore ice structure is dynamic and changing. It is a system that bears within itself simultaneously the means of growth and the means of destruction. What goes on at

any given time is a balance between the constructive and destructive forces. On the whole, as winter deepens the constructive forces dominate, and as spring progresses the destructive forces become dominant. It should be recorded, in passing, that the destructive factors have one member (sand-melting) that works everywhere at all times, while the rejuvenating factors work dramatically, but sporadically, on the ridge face where wave action is present.

LEGENDS FOR COLOR PHOTOS, SECTION C

Fig. 2(5). The frozen beach near the south edge of the Cook Plant construction site. Ice row on the surface indicates totally frozen beach. 15 December 1970.

Fig. 3(9). Southern edge of the Cook construction site. Frozen beach sand extending to the water's edge and showing small-scale undercutting and slumping due to wave action. Wave-tossed sand on the frozen surface at left. 17 December 1970.

Fig. 4(14). Frozen sand slab about 20 feet shoreward from the water's edge; the skim of snow has been brushed away to show the glaze of spray ice. At the sand-storage pile south of the Cook construction site. 29 December 1970.

Fig. 5(15). Simple tabular spray-snow icefoot along the beach north of the Cook plant site. Spray pattern visible on surface. 29 December 1970.

Fig. 6(20). The simple ice rampart condition. Undercutting and cracking in the foreground, and two newly developed blowholes beside the man in middle distance. 29 December 1970.

Fig. 7(22). The developed ice rampart, near the sand storage pile south of the Cook plant construction site. Ice cones developed around blowhole mouths. Numerous ice balls on the surface. 29 December 1970.

Fig. 8(24). The collapsed rampart condition. Near the south side of the Cook Plant property. Cracking, dropped blocks, and the water's edge in the foreground. Four regularly spaced blowholes have spewed sand onto the ice. The nearest blowhole is identified by a large block of dark sandy ice, which is shown in detail in Figure 9(25). 29 December 1970.

Fig. 9(25). Detail of Ridge A blowhole. Spray ice surface in background. Ice balls and sand in foreground. The blowhole in left background. Sun-warmed sand melting into ice in the ice block and other parts of the foreground. 29 December 1970.

Fig. 10(31). In the background is a push of brash (floe ice) which became Ridge B in the winter of 1969-70. 12 January 1970.

Fig. 11(34). Looking north from the temporary cofferdam at the Cook construction site. From right to left: Ridge A (showing sand); Ridge B (center); lagoon ice (left foreground to middle distance); and, at left, Ridge C developing substantial blowholes. A large field of loose ice lies outside (left) of Ridge C. 18 January 1971.

Fig. 12(36) Looking northward from the cofferdam at the Cook construction site. Ridge A, low and showing very sandy lumps, is at right close to the beach; Ridge B, from center foreground, is calving blocks as a result of the water pumped from the construction excavation; lagoon ice, from left foreground to center middle distance, is a relatively flat area of frozen ice floes; from left middle distance

Ridge C, with high blowhole cones and color evidence of extruded sand, completes the basic shore ice structure. Over the top of Ridge C in the left center distance a limited field of brash or floe ice is evident. 25 January 1971.

Fig. 13(74). From an overflight by Dr. O'Hara. An onshore view showing ridges A, B, C, and D with two areas of lagoon ice and a still outer area of floe or brash ice. With the Cook Plant in the background. 24 February 1971.

Fig. 14(77). An overview from the Cook Plant visitors' center of the basic ice-foot, two frozen lagoons, and two outer ice barriers when they were fully developed. Small ice cakes show in the open water beyond the second outer ice barrier. (Ridge D). 26 February 1971.

Fig. 15(80). Looking north along Ridge B at the north side of the plant site. Ridge A at right, the lagoon and Ridge C at left. 26 February 1971.

Fig. 16(85). The outer (lagoon) face of Ridge C looking south. Lagoon ice at right. 26 February 1971.

Fig. 17(88). North wall of a breach in Ridge C, natural condition. 26 February 1971.

Fig. 18(89). Sawed section of the same breach wall, showing component layers (mostly spray ice) tilting down and tapering toward the beach. 26 February 1971.

Fig. 19(90). Sawed section through a layer of spray ice and iceballs in the breach through Ridge C. 26 February 1971.

Fig. 20(91). Anticlinal pressure structure in the lagoon ice about 10 meters west of and parallel to Ridge C. Large sandy pancake ice incorporated in lagoon ice in background. 26 February 1971.

Fig. 21(92). Looking shoreward from Ridge D across hummocky lagoon ice to Ridge C. This ice gave access to Ridge D. 26 February 1971.

Fig. 22(93). Looking south from the back (shoreward) side of Ridge D. Ice blocks in the water appear to be grounded. White ice is fresh spray ice. 26 February 1971.

Fig. 23(95). Looking north along the face of Ridge D. Jon Barnes on the ice cone of a blowhole in Ridge D. Estimated to be 25 feet high, cone was the highest point in the local ridge. 26 February 1971.

Fig. 24(96). Closeup of surface of Ridge D after sand cover had been scraped away. 26 February 1971.

Fig. 25(116). At right a large and recently active blowhole in Ridge D; in the center the mild wave action of the day delivers slush/spray and iceballs in a breach of the ridge. 2 March 1971.

Fig. 26(118). A reentrant into the face of Ridge D, showing pancake ice, ice balls, and slush enough in the water to cause it to have a grey color. 2 March 1971.

Fig. 27(126). Looking westward at about 1000 from the visitors' center across the icefoot to broken second lagoon ice and an isolated portion of Ridge D. A saw-cut made in the wall of a breach in Ridge D shows near the right end of the isolated block. 3 March 1971.

Fig. 28(127). Same view as the preceding, but taken at about 1400. The loose second lagoon ice of that morning has been swept away by an increasingly rough sea from the northwest. Note the saw-cut of the day before near the right end of the Ridge D block. 3 March 1971.

Fig. 29(129). View northwestward from Ridge B to newly augmenting Ridge C. Spray/slush ice being thrown over the ridge and covering the old sandy surface. 3 March 1971.

Fig. 30(130). Detail of the surface of Ridge B at the time Ridge C was receiving augmentation. Sun-warmed sand has melted into the ice and accumulated as a surface lag-concentrate. Differential melting of iceballs in apparent proportion to the sand they contained. 3 March 1971.

Fig. 31(131). Extensive augmentation of Ridge C continuing, with an active blowhole. 3 March 1971.

Fig. 32(137). View southward along the top of Ridge C. Slush and spray coming over the ridge face, and an active blowhole, are shown. 3 March 1971.

Fig. 33(140). Wave breaking on the face of Ridge C; spray, slush, and iceballs of several sizes being thrown onto the ridge. 3 March 1971.

Fig. 34(141). View northward from the cofferdam. Ridges A and B are low, sand-laden and melting. Loose lagoon ice, and only pieces remaining of Ridge C. 5 March 1970.

Fig. 35(148). Ridges A and B low and sand-laden; lagoon ice refrozen; remnants of Ridge C (with some recent accretion?) at left. 16 March 1970.

Fig. 36(154). Looking northward along the beach from the cofferdam. Ridges A and B are severely melted and sand-covered. The lagoon ice is melted, and Ridge C is represented by isolated chunks. 23 March 1970.

Fig. 37(164). Beginning of the no-ice spring condition. A small ridge of sand along the north wing of the cofferdam in the foreground possibly represents the sand that had been incorporated into Ridges A and B. 30 March 1970.

Fig. 38(150). View northward along the beach of Cook site. Ridges A and B are low and sand-laden. Ridge C is still high and has some white-ice addition but its jagged lakeward edge indicates attrition along its face. 17 March 1971.

Fig. 39(152). View northward along the beach from the plant site after the storm of 19 March 1971. Large blocks of Ridge C ice have been pushed ashore, destroying Ridges A and B. Water near shore is heavily loaded with slush and iceballs. 22 March 1971.

Fig. 40(157). Looking north along the beach; showing the beginnings of the redevelopment of a new icefoot. Wreckage of earlier shore ice in foreground has been cemented by spray ice. Rough ice formed from slush, ice cakes, and iceballs shows at the left. Remnants of the earlier shore ice remain as blocks of ice and sandy ice up on the beach. 25 March 1971.

Fig. 41(158). Blocks of sandy ice, believed to be from old Ridge A, on the beach north of the Cook site. White spray ice and iceballs from the storm of 19 March cover the blocks. 25 March 1971.

Fig. 42(159). Wreckage of older ice ridges on the beach near Bridgman south of the Cook plant site. Some deposition of new spray ice along the left. Displaced blocks of sandy ice in the foreground. 25 March 1971.

Fig. 43(161). "Quarrying"of frozen beach sand where ice frozen to the beach has been moved when the old shore ice was displaced in the storm of 19 March. Near Bridgman. 25 March 1971.

D. EFFECTS OF EXISTING THERMAL DISCHARGES ON LOCAL ICE BARRIERS

Concerned citizens, in opposing the construction of power generating stations, commonly raise the point that the plants' discharges of waste heat will "melt the shore ice and allow the winter waves to produce added erosion of our beaches." During the past two winters we have spent substantial time and effort to ascertain from existing thermal discharges the degree to which there is evidence for their fear.

During these two winters we have: 1) carried out aircraft flights over the shores and thermal plumes of Lake Michigan; 2) maintained a scheduled photographic surveillance program to record the shore ice conditions at the Cook Plant site; and 3) carried out on-foot photographic expeditions to record changing ice conditions at the Cook Plant site and at the sites of existing thermal discharges. Winter operations of 1969-70 constitute Part V of our report series.

From these activities we have derived abundant evidence that the shore ice along the Michigan shore has the complex structure that Marshall (1966, Fig. 28)* called "the storm icefoot, lagoon, and outer barrier." The method of formation of this compound structure, and details of what the structure is, are discussed in Section C of this report.

Our data indicate that the concerned citizens are probably speaking of Marshall's complex of inshore ice structure which is present and frozen solid with sufficient consistency to be probably the one upon which they have walked, and from which they have drawn their correct conclusion that it protects the beach from winter wave action.

The icefoot consists of two to four ridges of ice very close to shore.

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*Marshall, E. W. 1966. Air photo interpretation of Great Lakes ice features. Special Report No. 25, Great Lakes Research Division, University of Michigan, Ann Arbor, Mich. ix and 92 pp., 64 figures.

Along the east shore of Lake Michigan we have found two ridges to be the rule. These ridges are solidly grounded on the beach and just off the beach and are usually laden with sand incorporated into the ice. Outside (lakeward) of these ridges for a distance of a few tens of feet ice floes have amalagamated into an ice sheet. This is the "lagoon" referred to by Marshall. Outside the lagoon there forms a heavier grounded outer ice ridge, the "outer barrier" of Marshall. This complex of two inshore ridges, a frozen lagoon, and an outer barrier has been surprisingly consistent along the eastern shore of Lake Michigan during the two winters of observation.

It is to the integrity of this complex of three ice ridges and a frozen lagoon, in the presence of thermal discharges, that this report addresses itself.

Our efforts in this connection during the winter of 1970-71 have not been completely successful; in the far northern part of the lake solid ice was found, but the small plants there were having little melting effect. In the southern three-quarters of the lake, broken ice was the rule on the days when we had overflights or shore expeditions to outfalls of operating plants. Perhaps our greatest success has been to obtain, this winter, pictures of the effects of the only two submerged outfalls that we know of to date: the Traverse City generating station and that of the DuPont Chemical Company at Montague, Michigan.

Dr. O'Hara overflew the Michigan shore from Big Rock to Grand Haven on 18 February before bad weather forced the abortion of the flight; on 24 February he flew over the Cook, Palisades, and Campbell plant sites; on 17 March he overflew the southern end of the lake from Bailly Station in Indiana to Manistee, Michigan; and on 10 March W. L. Yocum made a shore expedition to the outfalls of the Campbell and Michigan City generating stations.

Despite our efforts, the results of our 1970-71 investigations of the effects

of thermal plumes on shore ice conditions are presented in only 16 slides to supplement the results already presented in Part V (April 1970).

In Figure 1 the ice conditions at Big Rock Nuclear Station are shown. Shore ice ridges reach up to, and into, the discharge channel. 18 February 1971.

Figure 2 shows that shore ice is present behind (inshore of) the submerged outfall of the generating station at Traverse City. 18 February 1971.

The small (7500 gpm) submerged outfall of the DuPont Chemical Company at Montague was recognized in the middle three-quarters distance of a long-distance view (Figure 3) that contained sufficient landmarks for recognition. It makes a small melt-hole between the basic shore ice and an outlying ice barrier. 18 February 1971.

The plume from the Consumers Power Campbell Plant at Port Sheldon, Michigan, on 24 February 1971, is presented in Figure 4. This picture was taken far enough away to encompass the whole effect of the plume and includes at least three fishermen in the slightly steaming plume. It shows a shore with melted-off shore ice, but it also shows a shore with no visible evidences of erosion. We suggest that the current from the discharge channel constitutes a wave-breaking force that acts to protect these beaches.

The conditions of the outfall at Campbell Plant on 10 March (after snow and a cold period) are shown from the shore in Figures 5, 6, and 7. These figures constitute a south-to-north panorama of the Campbell plume. A heavy ridge of ice lay, at this time, completely around the Campbell plume. Ten fishermen are shown in the plume.

Figure 8 is of the discharge channel at the Palisades Plant of Consumers Power Company, near South Haven, Michigan on 24 February 1971. The two inshore ridges of the icefoot reach up to the discharge channel flume structures; the frozen lagoon and outer barrier ice ridge are disrupted by the water-flow (with

no heat) from the plant.

Figure 9 gives a distant view of ice conditions at NIPSCO's Michigan City generating plant on 17 March 1971. The discharge channel is at the right middle distance with ice on both sides.

Figure 10 gives the ice conditions in Michigan City harbor on 10 March 1971. Ice-coated riprap and sheet piles lie along the front right side of the picture but in the right three-quarters distance is a heavy curving vertical-faced rampart of shore ice.

Figure 11 depicts the plume from Michigan City's generating station in floe ice on 10 March. The plume enters from left foreground. Michigan City lighthouse (at the outer end of the main breakwater) shows at the right center edge.

Figure 12 presents the conditions of shore ice at the NIPSCO Bailly Station on 17 March 1971. Shore ice reaches up to both sides of the iron discharge flume. The offshore circular intake structure lies at the edge of blue water, and a visible plume of blue water emerges from the discharge flume.

Figure 13 shows the discharge of a small two-headed creek between Palisades and South Haven which (with no man-made heat) has on 17 March 1971 produced a greater destruction of shore ice ridges than had the plume of Bailly Station on the same day (Figure 12).

Figure 14 (also on 17 March 1971) shows, in about the same scale as Figure 12, the disruption of shore ice by the outlet flow of the Grand Marais Lakes between Stevensville and Bridgman, Michigan. The outflow from Grand Marais Lakes is less than Bailly Station's pumpage, yet disruption of shore ice at Grand Marais is worse than at Bailly Station's flume.

Figure 15. An unidentified creek between New Buffalo and the Cook Plant site has melted almost through the basic shore ice structure. 17 March 1971.

Figure 16 is of shore ice destruction by an unidentified creek north of

Grand Haven. 17 March 1971.

In both the latter cases the basic shore ice structure is nearly breached, a condition more advanced than observed at Bailly station.

The evidence available to us from our ice studies during the winters of 1969-70 and 1970-71 does not show that discharges of waste heat cause extensive melting of shore ice with resulting exposure of the beaches to wave erosion, as claimed by concerned citizens.

Instead, our data show that the usual outfall structure, a sheet-pile flume leading out into the water, will have shore ice continuing up to the very sides of the flume. The unconfined outfall channels of Big Rock and Campbell stations have, in both winters, shown different behavior. Big Rock each winter melted a narrow channel of limited length outward into the solid sheet ice of Little Traverse Bay and shore ice came up to the very edges of the outfall canal. At Campbell there has been, both winters, a considerable area of shore ice melted, but beach erosion has not been evident; perhaps the current from the discharge channel lessens the strength of wave action.

The unconfined natural mouths of even small streams appear to be capable (without man-made heat) of destroying substantial amounts of the protective shore ice. We believe that the apprehension the concerned citizens express has resulted from their observations of ice destruction at the unconfined mouths of natural streams. Reasoning from the consistency with which even short outfall flumes at power stations have protected the shore icefoot, we suggest that the concerned citizens could beneficially agitate for the construction of shore discharge flumes at presently unconfined stream mouths.

The Probable Effect of the Cook Plume on the Local Ice Barrier

The whole thrust of our studies of the ice barrier in the area of the Cook Plant site has been to obtain a background of information and experience from

which to draw a reasonable conclusion about the probable effect of the Cook Plant's future discharge plume upon the shore ice at and near the plant site.

In addition to the mode of formation of the shore ice and its structure at maturity, it was necessary to obtain certain distance measures. The construction of the temporary harbor provided one of these: a means by which to scale off distance on aerial photographs.

Personnel of Mr. Lawson's office kindly provided the dimensions of the temporary harbor, of these, the 447 foot length (east-west) of the harbor's south wall proved applicable.

Other needed distances and dimensions were provided by a map of the Cook Plant ice made on 2 March 1971 by Dr. O'Hara and Jon Barnes. Distances in this map were obtained by a combination of triangulation and pacing. Their map of ice conditions on 2 March is given in Figure 17.

During Dr. O'Hara's overflight on 17 March 1971 he photographed the mature ice structure at Cook when the four ice ridges and two lagoons were present without the complication of an outer ice field. In this photograph the distances out to Ridges C and D, as mapped on 2 March, were used as checks in scaling distance with the length of the south harbor wall as the measuring unit. The checks were adequate, and the length of the south harbor wall was then used to locate the two future outfalls of the plant. These, and identified parts of the ice structure, are shown in Figure 18.

In this figure the 1159'6" distance offshore to the outfalls (FSAR, vol. 1, drawing 12-5961) has been scaled off and the outfall positions indicated and labelled.

We see, and have evaluated, several facets in the question of whether the Cook Plant's thermal plume will produce serious melting of the shore ice.

First, the mode of formation of the icefoot is such that storms from opposite

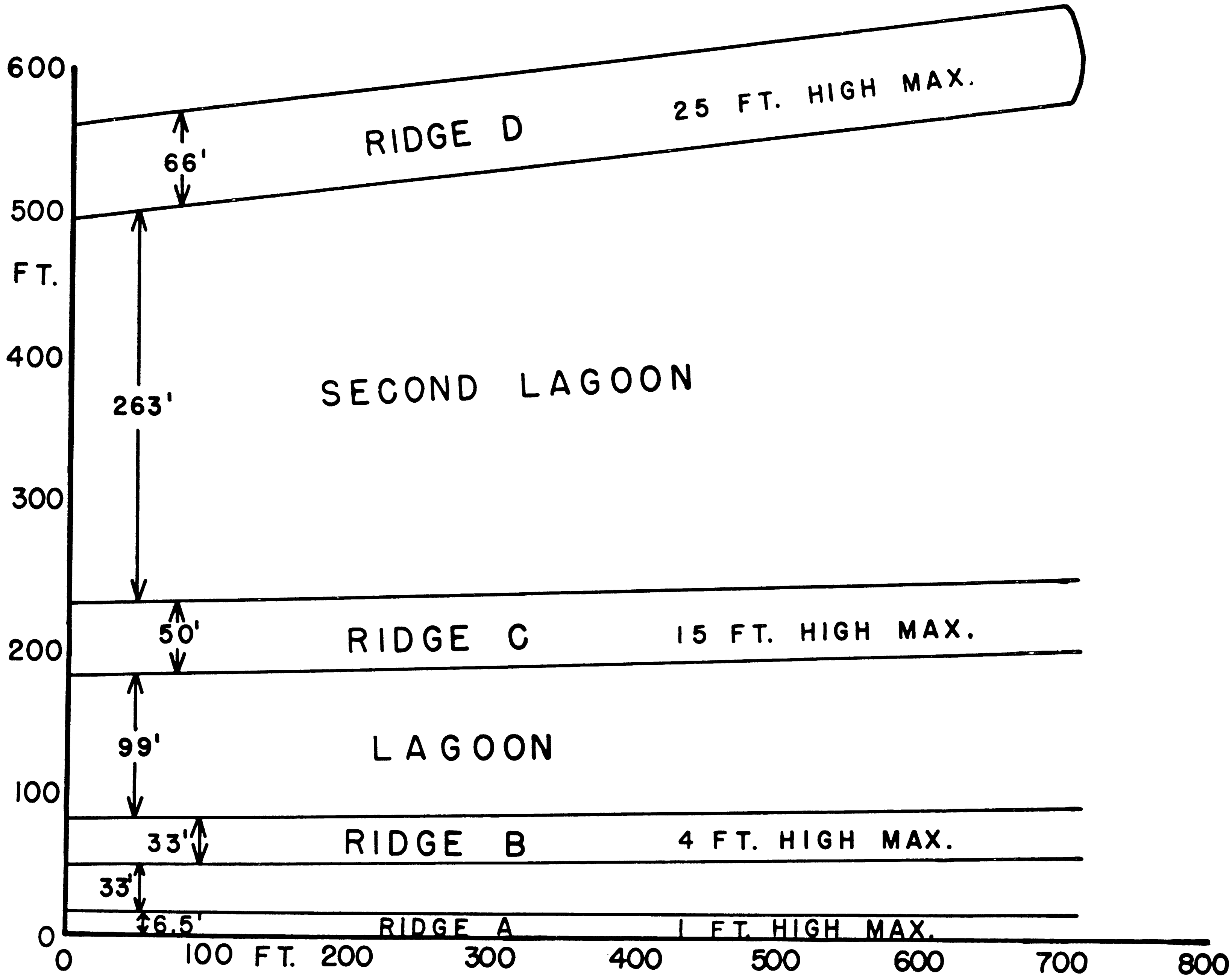

FIG. 17. Distances and dimensions on the shore ice structure on 2 March 1971.

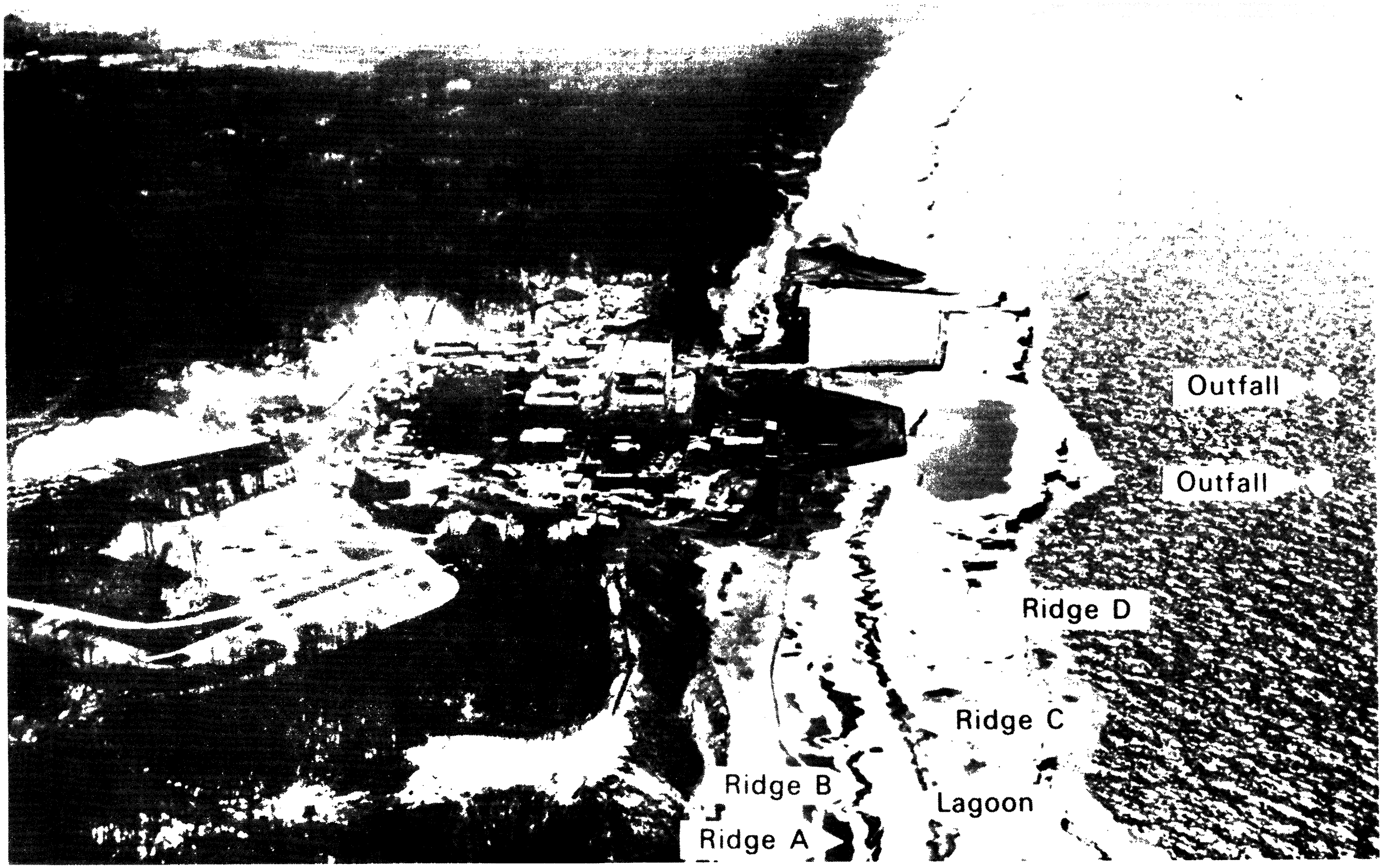

FIG. 18. The positions of the Cook Plant outfalls relative to the mature shore ice structure. Photo by Dr. O'Hara on 17 March 1971.

directions can construct it, even with a plume present, on both sides of the outfall. We have tried to illustrate this in Figures 19 and 20. Even if ice is melted in the area where the wind pushes the plume ashore, the ice in other directions will be augmented, and storms from opposite directions will provide the mechanism for rebuilding any melted ice.

That part of Ridge A which is on the beach is beyond the reach of plume water except during storms when air-cooled spray from the cooler part of the plume water could reach it. The offshore outfalls of the Cook Plant would keep the warmest water of the plume offshore.

We believe that a series of storms from different directions constitute the mechanism by which the observed shore ice behind (inshore of) existing plumes is formed.

Although plume directions are influenced by wind, they are also influenced by currents, with net plume direction being a resultant of the wind and current vectors. At the Cook Plant site the predominant alongshore current will provide a parallel to shore component of the direction of plume movement, resulting in more time, more distance, and more cooling before the Cook plume could reach the beach during an onshore wind.

The outfalls of the Cook Plant will be only six inches less than 1160 feet off the shore, and in a region where the predominant current is northward parallel to shore (but where southward current parallel to shore does occur). This is also an area wherein winds from off the shore are relatively unimportant because they must descend from the height of the sand-dune shoreline before they can get sufficient contact with the water surface to set up offshore currents. Offshore movement of the Cook plume is expected to be rare for this reason.

Winds from south-southwest clockwise around to north-northeast are unaffected by the dune shoreline; from these directions a wind-induced direction component

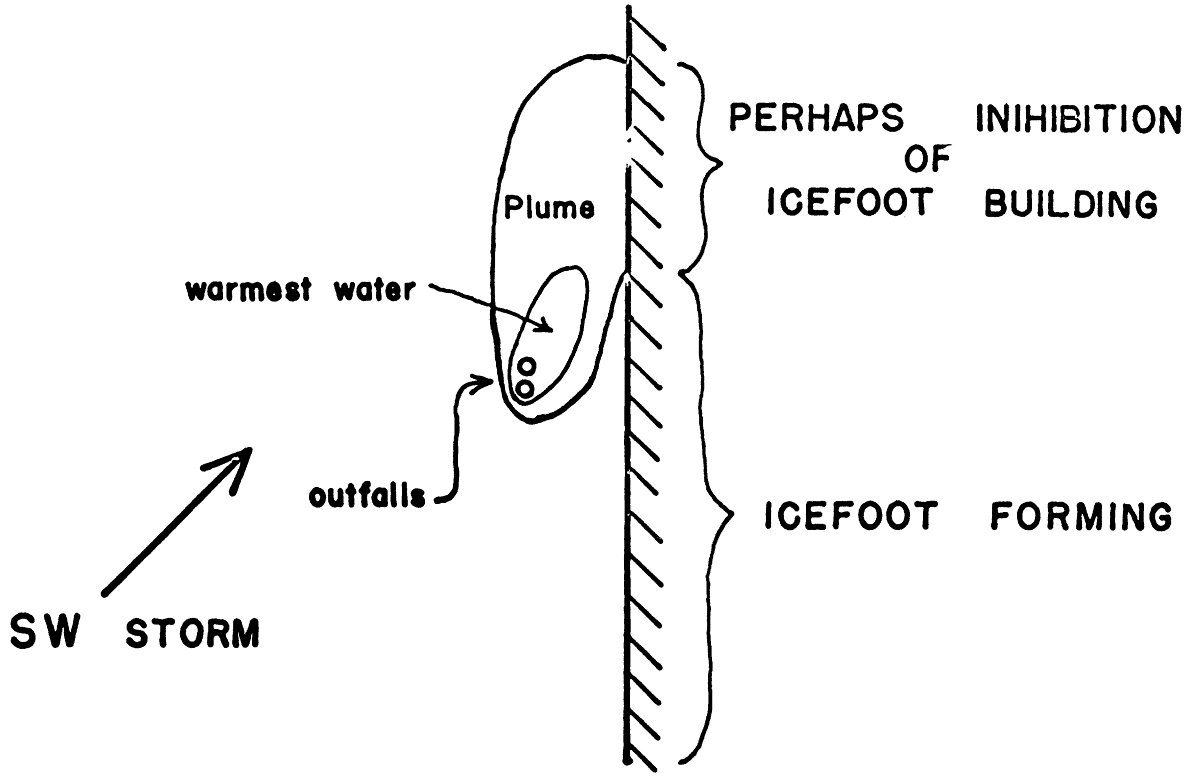

FIG. 19

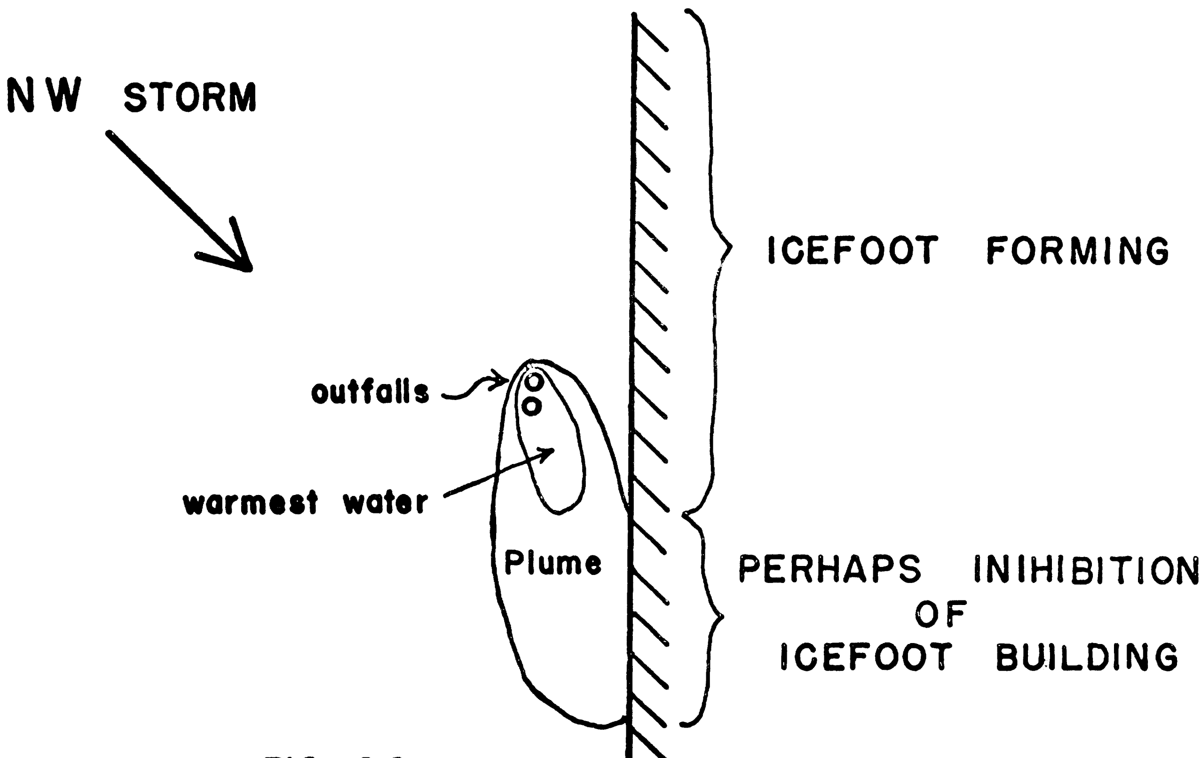

FIG. 20

FIGS. 19 and 20. Mechanism of formation of a continuous icefoot in the presence of a plume, by a southwest storm followed by a northwest storm.

can be added to the Cook Plant plume.

These winds, when blowing from the southwest quadrant (south to west), push water against the shore where it is deflected to become a northward alongshore current, when these winds are from the northwest quadrant (west to north) the water they push slides along shore as a southward alongshore current.

Typically the situation off the Cook Plant site indicates an alongshore current of greater or less strength running either northward or southward. To be added to this condition are movement components of the warm plume water that result from direct wind pressure on the floating warm water.

The shoreline along the Cook Plant site is roughly NNE-SSW (23° - 203° to our best estimate). The relations of this shoreline trend to the directions of winter winds are significant in deciding the directions and importances of winter wind-induced components of plume direction.

Figure 21 is a modification of Figure 2.2-19 of the FSAR. This figure is a wind-rose depicting the time frequency distribution of winds from different directions during the winter. In the center of this wind-rose (in the space customarily reserved for the calms of wind) we have drawn the trend of the shore and shaded the landward side. The basic figure 2.2-19 is from Smith-Singer Inc., meteorological consultants to Indiana and Michigan Electric Company, to whom our thanks are rendered.

On the whole, winter winds from the northeast and southeast quadrants are from the land. What little wind-induced components of plume direction they produce are directed away from the shore.

Winds from north-northeast or south-southwest are essentially parallel to shore, and the components of plume-direction that they induce are also parallel to shore where they either reinforce or oppose the alongshore currents.

Winds from the southwest quadrant (those from between 190° and 210° are most frequent) produce wind-induced components nearly parallel to shore. Wind-

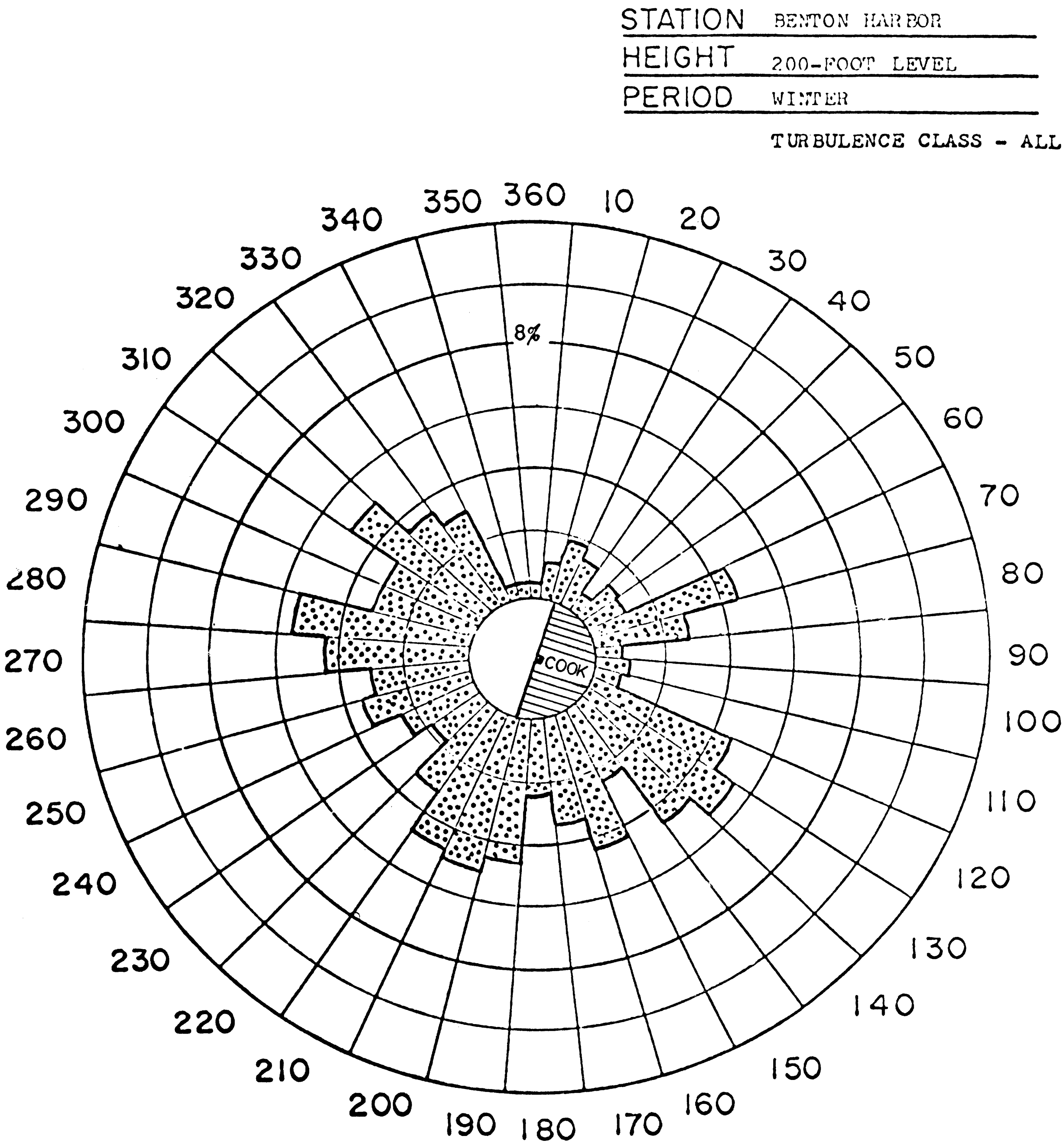

FIG. 21. The time-frequency distribution of all winter winds at the Cook site. Trend of the shoreline at the plant site is indicated in the center.

induced components of plume movement from these directions are so nearly parallel to shore that they probably can be considered as parallel.

It is evident that the Cook Plant's plume of waste heat will be blown toward shore by winds from several westerly and northwesterly directions. At the same time its direction will be modified by whatever alongshore current has been developed by the preceding wind. The wind-induced component and the alongshore current component are both variable and usually varying; the resultant of the vector addition of the two components at any instant determines the net direction of the plume movement at that time. Under varying westerly or northwesterly winds, and varying alongshore currents the Cook plume would wander randomly north and south of the plant site. Where the plume meets shore ice it can be expected to initiate the melting of the ice.

Because both the components influencing the movement of the plume will usually be varying, the resultant of their addition will seldom be the same; the result will usually be a plume-to-ice contact that is constantly shifting position.

It cannot, under these conditions, be expected that the shore ice of any one local area will be subject to the waste heat of the plume for more than short periods of time. Once the plume is out of contact with the local ice the normal winter regimen of the lake will resume; this includes both ice-destruction and ice-building.

Before proceeding further in this discussion it is necessary to point out that Figure 21 contains circles of wind frequency representing all the hours of winter wind observed during three years of observation at the Cook Plant site. Reading from the wind rose, the *most frequent* westerly wind is that from the 280° decade of wind directions; from this decade of direction (280° to 290°) the wind blows about 5.5% of the time. Similarly the *most frequent* northwesterly wind comes from the 310° direction decade about 5% of the time.

We judge that winds from 240° around to 340° can produce significant onshore

plume-direction components. Reading from the graph of wind frequencies:

Direction decade	240°	Wind frequency	2.5% of time
	250°		3.5%
	260°		3.0%
	270°		4.2%
	280°		5.5%
	290°		3.0%
	300°		3.0%
	310°		5.0%
	320°		3.5%
	330°		3.0%
		Total	36.2% of time

Thus, about a third of the winter winds blow from directions that could produce significant onshore components of plume direction. Some of these winds will be weak, and not productive of significant onshore components of plume direction; some will be strong.

All of the wind-induced onshore components of plume direction will add vectorially to the plume-direction component of the alongshore current, which will vary in strength.

During about two-thirds of the winter the plant's thermal plume will move alongshore or offshore.

In our experience, the natural forces of ice-building and ice-destruction are always present during the winter; one or the other dominates as appropriate conditions develop. During the two-thirds of the winter when the Cook Plant plume will not have significant contact with the shore ice, these natural forces will be in control. During that third of the winter when the Cook Plant plume could reach the shore ice these natural forces will continue to be operative on every part of the shore ice that the plant's thermal plume is not reaching at that time.

The Cook Plant thermal plume appears, at this time, to be an ice-destructive force potentially operative about a third of the time in winter. During this time it will be a destructive force wandering randomly along the shore, and staying in

contact with the shore ice for very limited periods at any local point. Since its ice-destructive effect will be always preceded and followed by the natural forces of ice-building and ice-destruction, we conclude that the effect of the Cook plume on local shore ice will be only a limited diminution in the amount of ice present.

LEGENDS FOR COLOR PHOTOS, SECTION D

Fig. 1. The conditions of ice and the thermal plume of Consumers Power Company's Big Rock Nuclear Station on 18 February 1971. Shore ice ridges reach up to, and into, the discharge channel.

Fig. 2. The two outfalls of the Traverse City, Michigan, Generating Station. At the right in front of generating station is the melt-hole of the plant's submerged outfall. Shore ice ridges are evident alongshore behind the melt-hole of the submerged outfall. 18 February 1971.

Fig. 3. The melt-hole of the submerged outfall of the DuPont Chemical Company at Montague, Michigan. The small melt-hole is visible in the middle three-quarters distance between the basic shore ice structure and an outlying ice barrier. 18 February 1971.

Fig. 4. A distant view of the complete plume from Consumers Power Company's Campbell Plant at Port Sheldon, Michigan. The slightly steaming plume has melted the adjacent shore ice, but the shore shows no evidence of erosion. At least three wading fishermen are visible in the plume. 24 February 1971.

Fig. 5, 6, and 7. A south-to-north panorama of the plume of the Campbell Plant on 10 March. A heavy ridge of ice lies completely around the Campbell plume. Ten fishermen are present within the plume in the three photographs. 10 March 1971.

Fig. 8. The discharge channel of Consumers Power Company's Palisades Plant near South Haven, Michigan. The two inshore ridges of the icefoot reach up to the discharge flume structures. The frozen lagoon and outer barrier ice ridge are disrupted by the water-flow (with no heat) from the plant. 24 February 1971.

Fig. 9. A distant view of Northern Indiana Public Service Company's Michigan City generating station. The plant's discharge channel is at the right middle distance, and has ice on both sides of it. 17 March 1971.

Fig. 10. Ice conditions in Michigan City harbor, looking eastward on 10 March 1971. Ice-coated riprap and sheet piles show along the front right side of the picture, but in the right three-quarters distance there is a heavy curving vertical-faced rampart of shore ice within the enclosed harbor.

Fig. 11. The plume from the Michigan City generating station, as visible in the floe ice of the harbor; the plume enters from the left foreground. 10 March 1971.

Fig. 12. Shore ice conditions at NIPSCO's Bailly Station on 17 March 1971. Shore ice reaches up to both sides of the plant's iron-sheet discharge flume. The plant's circular stone intake structure lies offshore at the edge of blue water, and a visible plume of blue water emerges from the discharge flume.

Fig. 13. The discharge of a natural two-headed creek between Consumers Palisades Plant and South Haven, Michigan. The creek, with no man-made heat, had produced more destruction of the shore ice ridges than had the plume of Bailly Station on the same day (see Figure 12). 17 March 1971.

Fig. 14. Disruption of shore ice by the outlet flow from the Grand Marais Lakes near Stevensville, Michigan. 17 March 1971.

Fig. 15. Disruption of shore ice by an unidentified creek between New Buffalo, Michigan, and the Cook Plant site. 17 March 1971.

Fig. 16. Shore ice destruction by an unidentified creek north of Grand Haven, Michigan. 17 March 1971.